Arcs in Inert Gases.* II

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Arcs in *pure* inert gases between electrodes of pure metals have been found impossible to maintain under ordinary conditions, whereas they are easy to maintain if the gas is slightly contaminated. (1) For highly purified iron in argon, helium and neon, and highly purified silver and zinc in argon, the arc discharge is inherently unstable. The cathode spot darts rapidly up and down the electrode, and finally goes out at values of open circuit voltage, short circuit current, pressure of the arc atmosphere, and electrode separation at which a stable arc is ordinarily obtained when slightly less pure elements are used. We conclude, therefore, that the degree of purity of the elements of metallic arcs in inert gases, and particularly the degree of purity of the gas, determines the boundaries within which stable arcing may occur. Further, for elements of a high degree of purity the boundary values of the region of unstable operation are quite definite and readily determinable experimentally; beyond these boundaries much more stable arcs are encountered. (2) The extinction of an unstable arc is not characterized by any marked change in the current or voltage of the arc at the instant immediately preceding extinction. (3) Higher purity of the electrode material and of the inert atmosphere appears to move the voltage *versus* current curve in the direction of higher voltage.

INTRODUCTION

A PREVIOUS investigation[1, 2] revealed the impossibility of obtaining a stable, low current arc discharge between pure iron electrodes in a pure argon gas atmosphere. The arc was found to go out spontaneously. In the present paper certain of the boundary conditions of this previously observed phenomenon are reported, and in addition the phenomenon is found to extend also to silver and zinc arcs in argon, and to iron arcs in helium and neon.

The boundary conditions reported are the limiting values of three parameters: open circuit voltage, electrode separation, and pressure of the arc atmosphere—limiting in that they could not be exceeded without the authors' obtaining an arc which persisted for *at least five seconds. Such an arc the authors have arbitrarily classed as "stable."*

PURITY OF THE MATERIALS. APPARATUS DETAILS

The purest obtainable metals and gases were used for the tests. The iron was supplied by the magnetic testing division of the Westinghouse Company, and was guaranteed to have an oxygen content of less than 0.01 percent in addition to being particularly free from solid inclusions. The silver was obtained from Handy and Harmon of Bridgeport, and was declared to be 99.999 percent pure silver. Nothing was known of its gas content as received, but it was vacuum baked at about 600°C before use. The zinc was furnished by the New Jersey Zinc Company, and was stated to be spectroscopically pure. It too, however, was vacuum baked at 360°C before use in the experiments.

The argon was supplied in high pressure cylinders by the Cleveland Wire Works of Nela Park, Ohio, and was stated to have an impurity content of not greater than thirty parts per million, but before final use it was purified as described below. The neon and helium used were the spectroscopically pure grade which the Air Reduction Sales Corporation supplies sealed in glass, and were used as received. (The neon actually contained 0.8 percent of helium, but was otherwise spectroscopically pure.)

Two refinements of the apparatus used in the previous investigation consisted in adding a mercury vapor pump behind the rotary oil pump and in inserting a liquid air trap in the vacuum line at the inlet to the arcing chamber.

In the previous investigation the glass system was torched during evacuation. The present authors attempted to extend this precautionary measure by providing for the baking out of the arcing chamber as a whole, and the chamber design they finally adopted is shown to scale in

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[1] Doan and Myer, Phys. Rev. **40**, 36–39 (1932).

[2] Doan and Myer, Elect. Eng. September, 1932.

Fig. 1. Unfortunately, the baking operation had to be dispensed with, for it was found that it could not be carried out, even under vacuum, without its producing on the freshly cleaned electrodes a thin film, apparently of oxide. The authors assume that the film was produced by active gases thrown off the glass walls or other parts during the baking. In the tests the arc was never run so long that the walls became hot enough to give off gas, and the electrodes were never found to have developed an oxide film.

The misch metal arc shown attached to the arc chamber proper (Fig. 1) constitutes the scavenger eventually adopted. It was used, however, only for the argon tests. The solenoid pick-up used to move the anode assembly was another refinement adopted in the present work.

The duration of a discharge was measured with a stopwatch, and the five second criterion for stability was selected in part because arcs of much longer duration melted the electrode tips. The possibility of melting also caused the authors to fix ten amperes as the maximum current to be used.

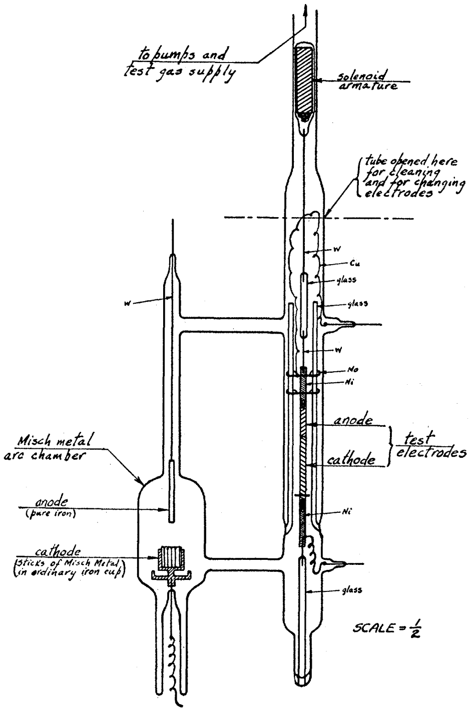


FIG. 1. Arcing chamber and misch metal arc chamber.

The measuring circuit followed the conventional arrangement, and the variable voltage source and series resistance enabled either open circuit or short circuit current to be held constant while the other was being varied. The vacuum pump and adjustable solenoid provided for variation of the other two parameters—the arc atmosphere and electrode separation, respectively.

OBSERVATIONS AND RESULTS

The general character of the unstable arcing effect was described in references (1) and (2). A similar description fits the present arcing effects. Thus, during the five second interval immediately following the strike the unstable arc would vary its length by several hundred percent as the cathode spot darted up and down the side of the electrode, and then suddenly would go out.

Only for iron electrodes were all three parameters varied independently in each of the three gases, A, He and Ne. The maximum possible values of voltage and current for unstable arcing (which are, of course, also the minimum required values for stable arcing) are shown in Figs. 2 and 3.

Fig. 2 shows the effect of varying the pressure of the arc atmosphere. The effect is small in argon and also in neon so long as the discharge remains that of an arc. At 19 cm in neon, however, the discharge becomes a glow, and the minimum required open circuit voltage for stable arcing at once increases by a factor of more than two. All of the helium curves represent a glow type of discharge and the minimum re-

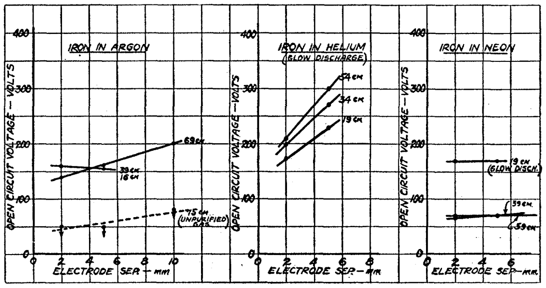


FIG. 2. Minimum open circuit voltage required for stable arcing; effect of pressure of arc atmosphere. (Short circuit current = 3.0 amperes.)

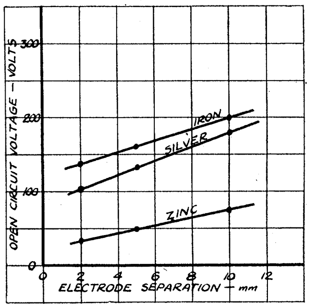


FIG. 3. Minimum open circuit voltage required for stable arcing; variation with electrode material. Gas = argon, pressure = atmospheric, short circuit cur. = 3.0 amp.

quired voltage for stability is seen to increase with the pressure.

The argon curves also show the effect of contamination in the atmosphere of the arc. For unpurified argon the minimum required open circuit voltage is only about one-third that required for purified gas.

Fig. 3 shows the variation of open circuit voltage requirements with electrode material. Zinc is seen to yield a stable arc at much lower open circuit voltages than will iron and the requirements for silver lie intermediate between those for the other two.

The current boundary of stable arcing was studied up to 8.5 amperes short circuit current, but the measurements are not yet completed.

OSCILLOGRAMS AND MOTION PICTURES

In exploring the cause of extinction some twenty-two oscillograms were taken. Fig. 4 shows the initial strike between pure iron electrodes in a slightly impure argon atmosphere—it represents a stable arc. Iridescent oxide colors appeared about the cathode tip for several millimeters below the usual sputtered region indicating that an oxide film had formed during the discharge, and showing that the gas was impure. Twenty subsequent strikes were made with these electrodes in the same atmosphere, the first four lasting more than 20 seconds, and all lasting longer than 7 seconds with an average around 15 seconds.

Fig. 5 shows the seventy-first strike in a system which was scavenged by the misch metal arc. The strike is seen to have lasted only about

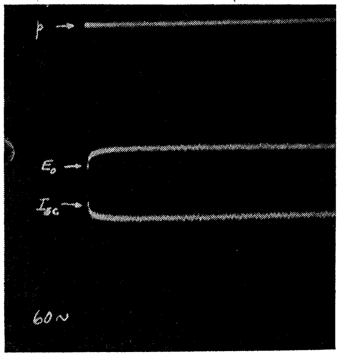


FIG. 4. Initial strike—pure Fe electrodes in unscavenged A. Stable arc.

1.1 seconds, with the final break occurring very suddenly and at very high speed. The zero of voltage (E_{sc}) and short circuit current (I_{sc}) were not drawn separately in this film, but were about where the arrows indicate.

Sufficient of the 60 cycle trace shows at the lower right for the time of the discharge to be calculated. This trace shows particularly well the rapid and random variations of current and voltage in the unstable arc, and the extremely rapid and sudden final break of the arc.

Motion pictures of the typical arc recorded in Fig. 5 were taken also in the hope of correlating the wandering of the cathode spot down the side of the electrode with voltage and current changes in the arc. The motion picture camera was, however, of only standard speed, and not nearly fast enough to record the rapid fluctuations in arc length as the cathode spot wandered. Three successive pictures on the film were found, however, which caught the arc immediately before and immediately after the cathode spot had wandered way down the side of the cathode, and Fig. 6 gives some idea of the long arcs which this erratic wandering sometimes involved.

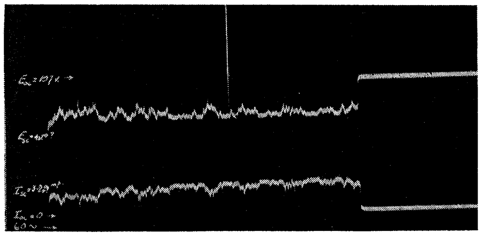


FIG. 5. Seventy-first strike—unstable arc.

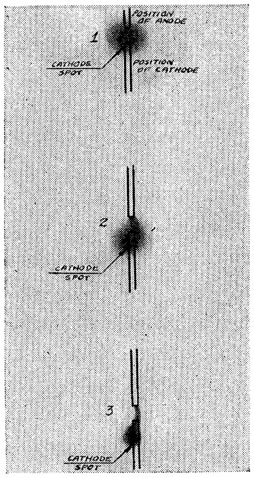


FIG. 6. Successive standard speed motion pictures of an unstable arc. Arc struck in same system as that for arc of Fig. 5—arc is seen to be lengthening at cathode end.

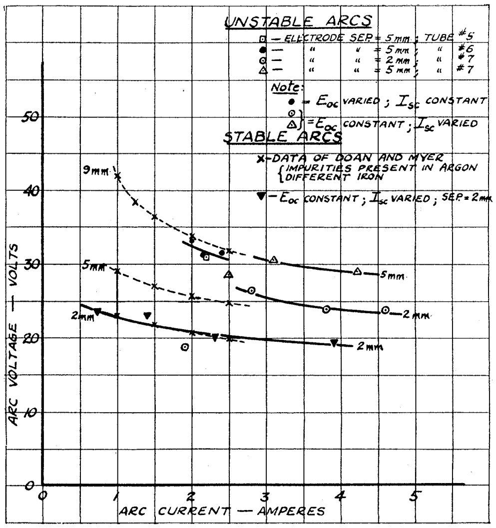
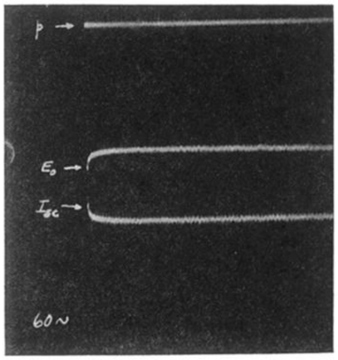


FIG. 7. Static characteristics of stable and unstable arcs; effect of impurities in the gas. Pure iron in argon, atmospheric pressure.

Further examination of Fig. 5 shows that the *minimum* values of arc voltage and maximum values of arc current lie on straight lines which are parallel with the "zero lines." It seemed logical to assume this minimum voltage (and maximum current) condition to be that obtaining when the arc was as short as possible, that is, when the cathode spot was on the tip of the cathode rather than somewhere down its side. (The anode end of the discharge always emanated from the tip of the electrode and, accordingly, need not be mentioned in considerations of arc length. The latter is always taken as the luminous path to the cathode spot.) Adopting this assumption we have at once an accurate method of locating the *E versus I* curve for arcs which last even only a fraction of a second, and which, therefore, could not be observed on dead beat instruments.

This method of locating the *E versus I* curve looked so promising that it was decided to use it to check the *E versus I* curves determined in reference 2 for pure iron in slightly impure argon in which investigation it had been necessary to use dead beat instruments and two observers. For the attempted confirmation the present authors used argon from the tank, that is, without scavenging it, and oscillograms taken at 2 mm separation. Four different short circuit currents yielded the static characteristic shown by solid inverted triangles in Fig. 7. The close check of this curve with the data of the previous investigation is somewhat surprising since the iron of the electrodes used this time was distinctly different from that used previously, having been prepared by a different company under a different process, and known to have only 0.01 percent of oxygen whereas the electrodes used previously contained some 0.07 percent of oxygen. Apparently, the condition of importance for non-arcing is the purity of the inert gas; the purity of the electrodes seems to be relatively unimportant.

Three oscillograms of unstable pure iron arcs in scavenged argon for 5 mm electrode separations were taken and eight for 2 mm separations. On calibrating the oscillograms of these unstable arcs and plotting their traces as static characteristics (see Fig. 7) we find the characteristics located at definitely higher voltages than the corresponding curves for stable arcs.



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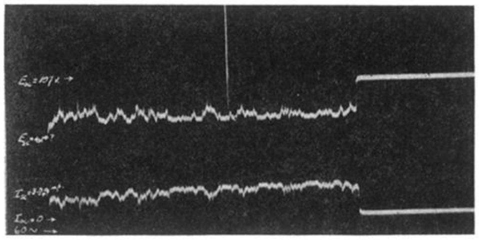
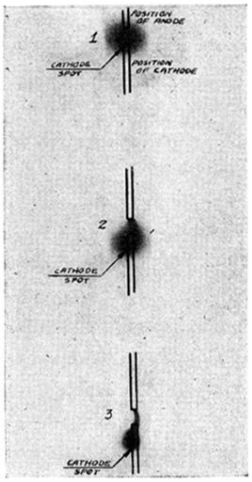


Fig. 5. Seventy-first strike—unstable arc.



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